EFFECT OF IN-FURROW STARTER FERTILIZER ON OKLAHOMA

DRYLAND WINTER WHEAT (*TRITICUM AESTIVUM L.*)

By

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Abstract: Little starter fertilizer research has been conducted on winter wheat in the central U.S. This study was carried out to compare different starter fertilizers placed in furrow during planting. Yield, test weight, and mineral concentrations were measured in two years across three trial locations around Stillwater, OK. In 2015, one location was abandon due to weed pressure. Lake Carl Blackwell (LCB) soil test recommendations showed no need for additional fertilizer, which resulted in no significant difference from any fertilized trial compared to the check. At the North 40 (N40) location, soil tests showed a need for P; however, no significant difference from fertilized plots above the check were noted. At the Perkins location soil test recommendations showed a need for P fertilizer and lime. This low soil test P and pH resulted in seven fertilizer applied treatments out yielding the check, but no significant difference between orthophosphate and polyphosphate fertilizers. Based on these results, starter fertilizers should be evaluated based on cost, and the soil test recommendations.

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CHAPTER I

Review of Literature

Introduction

Since Oklahoma statehood, winter wheat (*Triticum aestivum*) has been the mainstay crop in the state with an average of 2,028,248 hectares planted per year (National Agricultural Statistics Service, 2015). Although many of the hectares are used for both grazing and grain, wheat has been a consistent crop for grain only farming operations. While these grain only production systems continue to be profitable, the recent drought conditions as well as the declining grain prices have producers searching for more ways to increase production while limiting operating expenses. With the improvements in technology, as well as, the increase of fertilizer sources, producers now have the ability to use fertilizer in a more efficient way to decrease costs.

In-furrow starter fertilizer has been used in many winter wheat production systems for decades (Olson and Fitts, 1949). Additionally, increasing in-furrow applications should be smooth as growers have many options including older no-till drills are setup up to apply dry fertilizer with the seed. Furthermore, growers have many options in fertilizers to be applied. In Oklahoma commonly used fertilized used in-furrow are urea, diammonium phosphate (DAP), and monoammonium phosphate (MAP) (Zhang, 2006). In recent years, several new starter fertilizers have been commercially available for growers to use, however, little research have been conducted to determine the effect of these different types of starter fertilizers in no-till wheat production system in the Southern Great Plains.

Research

Starter fertilizer is the process of putting fertilizer within close proximity of the seed. These fertilizer applications can be placed in-furrow with the seed , within a few inches of the seed underneath the soil surface, or banded over the top of the seedbed. Starter fertilizer normally contains a mixture of nitrogen (N), phosphorus (P), potassium (K). However, with increasing yield of crops in recent years, other nutrients including sulfur (S) and zinc (Zn) have been increasing in demand and can be applied in both dry and liquid forms. In-furrow starter fertilizer application methods in cereal grain crops have been have been extensively studied. Corn is the most researched crop in this area and studies have been done in all production regions. When used correctly, in-furrow fertilizer applications have enhanced emergence and increased grain yield especially in fields where low soil test P or K has been documented (Kaiser et al., 2005). However, other research has found increased grain yield in high P testing areas when using starter fertilizers (Roth et al., 2003)

It has been documented that adequate application of N and P is crucial in creating sufficient root growth for winter survival, especially in winter wheat. According to Sander and Eghball (1999), N and P starvation of winter wheat in the fall could decrease tillering, which can result to reduced yield during harvest. Phosphorus can be supplied in fairly large amounts through banding or in-furrow methods without compromising germination; however, N must be used sparingly to prevent stand reduction from salt damage. This makes germination rate with in-furrow fertilizer applications one of the most critical and most widely researched topic. As far back as 1960, researchers have shown that significant amounts of N sources placed close to the seed can be detrimental to crop stand (Brage et al. 1960). This work, along with other research on salt based fertilizers, introduced the concept of salt index. Salt index is the measure of salt solution that a fertilizer excretes into the surrounding soil solution (Rader et al., 1943). When salt based fertilizers (i.e. urea, DAP, MAP) dissolve in soil moisture, they increase the salt concentration and result in higher soil solution osmotic potential. Whenever a fertilizer is able to change the osmotic potential of the seed area, it causes germination problems and reduction in stand count from the loss of moisture available to the seed (Laboski, 2008; Reed and Beaton, 1963). Studies have shown that any N containing fertilizer has the capability of causing germination problems when placed in high amounts close to the seed. Although putting down fertilizer with the seed could provide producers a more economical benefit (Kaitibie et al., 2002), growers need to consider N application rates of in-furrow fertilizers as not to hinder germination from over application. Generally it is best not to apply greater than 13 kg of N + K per acre with the seed, depending on soil type and moisture (Beegle et al., 2007).

Phosphorus is the second most common nutrient deficiency in Oklahoma. Lack of available P will impede root growth and tillering especially going in to winter (Sander and Eghball, 1999). Unlike N wherein deficiency can be fixed with in-season N application, Slaton et al. (2002) found that P needs to be applied at or before planting so as to prevent deficiency that will eventually cause decrease in final grain yield. Because P is immobile, placing it directly with the seed can allow it to be efficiently used without becoming inacessible in the soil profile (Boomsma et al., 2007). Research by Stewart and Miller (2000), has shown that when winter wheat was planted later into cooler soil conditions, response to P fertilizer improved. This could be a great benefit to growers in Oklahoma due to later potential planting due to environmental or mechanical delays. Oklahoma State University (OSU) recommends applying P fertilizer whenever the soil tests show less than 35 ppm (Zhang, 2006).

There are two major forms of phosphates available in the market today, polyphosphates and orthophosphates. Polyphosphate fertilizers, like the liquid fertilizer ammonia polyphosphate (APP), are generally the less expensive P source for producers. Orthophosphates, such as 9-18-9, can be found in many proprietary low salt starter fertilizers that are being marketed in the U.S. Orthophosphate fertilizers are procured from food-grade P sources, making it more expensive to use than polyphosphates. Phosphorus is taken up as orthophosphate by the plant (Schachtman et al, 1998). For polyphosphate fertilizers to be utilized by the plants, it must be reverted back to orthophosphate through the aid of soil microbes (Schachtman et al., 1998). However, studies have shown that cereal grain crops do not benefit from using orthophosphate over polyphosphate for total yields, even in low soil test P treatment areas (Dobson et al., 1970). Oklahoma producers using liquid starter systems commonly use APP as source of fertilizer. Currently, there has been little research done in Oklahoma comparing APP and dry fertilizers to the new proprietary orthophosphate in the market currently, especially with the high yielding winter wheat varieties that are available today.

Another major essential nutrient is K. Potassium, has also been found deficient in Oklahoma soils (Zhang, 2006), but majority of the soils in state have optimum soil test level for K. Potassium is the most abundant cation in the plant, as it is important to many physiological processes. Protein synthesis, photosynthesis, enzyme activation, and osmoregulation mediation during tropisms, stomatal movements, and cell expansion are all affected by K in the plant (Maser et al., 2002) Research has shown that K fertilization will decrease stalk lodging in wheat (Beaton and Sekhon, 1985) Unlike P, Mallarino et al. (2011) have shown that unless there is a K deficiency, there is no yield benefit to include K in a starter. This research also showed that there was a possibility for increased growth with a K fertilizer whether soil tests called for it or not, but no yield increase was found. The use of KCl as a starter fertilizer has generally not been recommended for an in-furrow application because of its high salt index. Due to this problem, it is most often recommended as a broadcast application. Oklahoma State University recommends applying K fertilizer whenever soil test K is under 125 ppm (Zhang, 2006).

One potential response to potash in more coarse soils would be a chloride (Cl) response from KCl (0-0-60) application. Since there is no K response based off high soil tests, Cl would be the suspected nutrient response in this kind of environment. Research has shown that the positive response in crops where soil tests indicate a high level of K and where KCl is applied is attributed to the Cl response (Fixen et al., 1986). The same research also showed a yield increase due to disease suppression resulting from the Cl absorption. Because Cl is a mobile nutrient, and disease starts to show up in the spring, it would be more efficient to apply Cl with N top dress to treat a deficiency or disease. Although Fixen et al. (1986) reported that Cl is useful to treat disease in small grain production, Thomason et al. (2001) found inconsistent results in Oklahoma using Cl^- to control Take-all in winter wheat.

Calcium (Ca) and magnesium (Mg) are most often found deficient in low pH areas that have not been limed in several years. Most often, a pH correction with lime will correct any Ca deficiency there may be. If there is a Mg deficiency, dolomitic lime may be used as well. Oklahoma State University recommends applying Mg fertilizer whenever soil test show less than 50 ppm, while Ca should be applied at a soil test less than 375 ppm (Zhang, 2006).

Historically, secondary and micro nutrients such as sulfur (S), boron (B), and zinc (Zn) have not been a concern in Oklahoma winter wheat, but in the recent years wheat has shown S deficiency symptoms in some areas due to increased yield potential as well as environmental regulations that have resulted in decreased S deposition (Shannon, 1999). Kansas State University has found S deficiencies in wheat fields around the state which were low organic matter soils that were coarse textured and susceptible to leaching (Lamond, 1997). Sulfur plays a vital role in amino acid and protein production in the plant (Zhao et al., 1999). Sulfur is a very mobile nutrient in the soil and has been shown to test low in sandy, coarse soils. Research in corn has shown consistent increase in early plant growth with S as a starter fertilizer, although early growth responses were not always translated to yield (Kim et al., 2013). They reported that S fertilization increased corn yields when soil organic matter levels were at 2 to 4%. This would coincide with the fact that S is released from organic matter in the soil, of which Oklahoma soils are considered low. Oklahoma State University recommends a 20:1 ratio of N applied to needed S (Zhang, 2006).

Many of the newly released starter fertilizers contain micronutrients that are not generally needed in Oklahoma soils (Zhang, 2006). Although peanut producers have seen deficiency problems with B, it has not been a nutrient of concern for wheat producers in Oklahoma. If there is a B deficiency in a wheat field, it will most likely be found in weathered, sandy soils since it is a mobile nutrient. Boron fertilizer is generally inexpensive, but over application (by as little as half a pound) could result in toxic levels and a failed crop. It is important to know soil B levels before the crop goes into reproductive stage as deficiency signs do not show up until it is too late. Reproduction and grain set can be aborted through male sterility and reduced pollen germination because of B deficiency (Cheng and Rerkasem, 1993; Rerkasem et al., 1993). Oklahoma State University soil test recommends applying B fertilizer whenever soil tests are below 0.25 ppm (Zhang, 2006).

Zinc deficiency is normally found in course-textured and in neutral and calcareous soils. Wheat growers in far western Oklahoma have expressed concerns of running into Zn deficiency with their calcareous soils. Some micronutrients including Zn, Fe, Mn, B, and Cu are all less available in high pH environments (Zhang, 2006). It would be recommended to apply approximately 6 lbs of Zn fertilizer which would correct the deficiency for several years (Zhang, 2006).

Objective

The objective of this research project is to determine the effect of multiple starter fertilizers on winter wheat grain yield and quality. This research will compare yields across different fertilizer sources to establish a base on starter fertilizer management strategy for Oklahoma farmers.

CHAPTER II

Effect of In-Furrow Starter Fertilizer in Oklahoma Winter Wheat

Materials and Methods

Field trials were conducted in 2014-16 at Perkins {lat 35.99556°, long -97.04333°}, North 40 (N40) {lat 36.136785°, long -97.080773°} and Lake Carl Blackwell (LCB) {lat 36.140516°, long -97.284546°}, OK. All locations were on no-till and located within 48 km of Stillwater, OK and represented very different soil types and nutrient levels. Perkins location is a Pulaski fine sandy loam (deep, well drained, rapidly permeable flood plain soils that formed in loamy alluvial sediments of Holocene age), N40 location is a Kirkland silt loam (deep, well drained soils that formed in material weathered from clayey sediments over shale of Permian age), and LCB location is Teller fine sandy loam (fine-loamy, mixed, active Thermic Udic Agriustolls). Soil samples were taken at each location prior to planting to determine soil nutrient levels. Table 1 documents soil test results. In year 1, Perkins and LCB locations were established after wheat and N40 location after alfalfa. The experiment consisted of 12 treatments arranged in a complete randomized block design with three replications. Treatments were established based upon popular fertilizers used in the state of Oklahoma as well as regionally available fertilizer sources needing to be tested. A fully fertilized check (treatment 1), no in-furrow fertilizer applied, was incorporated to establish a response to in-furrow fertilizer. The three most commonly used commercial N and P fertilizer sources DAP, MAP, APP treatments 2, 3 and 10, respectively, were applied at rate so that total P applied, 15 kg P ha^{-1}, would be balanced across treatments. The products MES10 and MESZ (Mosiac Co., Plymouth MN) where incorporated into the study to evaluate the response to S and Zn in treatments 4 and 5. The product MES10 (12-40-0-10) is a MAP based fertilizer source which has had S incorporated into it while MESZ (12-40-0-10-1), also MAP based has S and Zn incorporated into the source. Both of these products were applied at rates so that P was balanced with DAP, MAP, and APP treatments. Treatments 6 and 7 evaluated muriate of potash (MOP) and Apsire (Mosiac Co. Plymouth MN) at an application rate of 18.6 kg K ha^{-1}. Apsire (0-0-58-.05) is a MOP based fertilizer which has B incorporated into its crystalline structure. Two treatments evaluating specialty liquid sources were included at a balanced P rate of 15 kg P ha^{-1}. Treatment 8 evaluated a liquid 6-22-6-1(S) fertilizer (Nachurs Alpine Solutions, Marion OH) derived from urea, ammonium hydroxide, phosphoric acid, potassium hydroxide, and ammonium thiosulfate. This product has the claim of 100% of the phosphate is present in the orthophosphate form that is immediately available for plant absorption and metabolism. Treatment 9 had the same rate of liquid 6-22-6-1(S) but had the addition of the liquid product CornGrow (Nachurs Alpine Solutions, Marion OH). The product CornGrow has an analysis of (0-0-0-.4-.6-3.5) a copper, manganese, and zinc fertilizer is manufactured with 100% fully chelated nutrients. CornGrow is derived from Cu EDTA, Mn EDTA, and Zn EDTA and was applied at a rate of 2.33 L ha^{-1}. Treatment 11 evaluated a micronutrient seed treatment Awaken ST (Loveland Products, Loveland, CO). Awaken ST (6-0-1-5Zn-0.25Cu-0.25Fe-0.25Mn-0.03B-0.001Mn) was applied directly to the seed before planting at a rate of 3.9

ml per kg of seed, or .37 L ha^{-1}. Treatment 12 contained both Awaken ST at the same rate as treatment 11, but also contained DAP at 15 kg P ha^{-1}. Table 2 lists the treatment structure used in this study. The treatments used in this study will be able to compare the various products available to Oklahoma wheat producers. Varying products from dry to liquid, generic to proprietary, as well as fertilizers not normally used in-furrow such as MOP and seed treatments will all be evaluated. The salt index of each treatment, calculated by equivalent per unit of material, is included in Table 3. Plot size was 3 m (15 rows) wide by 6 m long with 6 m alley between replications. A 3 m Great Plains no-till drill set at 19 cm rows was used to plant the research plots and apply dry fertilizers in-furrow (Figures 1 and 2). Planting rate was calibrated at 96 kg ha^{-1}. The only seed that was treated were treatments containing Awaken ST, and it was applied using a concrete mixer and spray nozzle. A CO_2 powered liquid sprayer system was also set up for easy exchange of liquid fertilizers from treatment to treatment. To clean out liquid fertilizer between treatment applications, the system was flushed with clean water and then blown out with compressed air. For dry fertilizer changes, all fertilizer granules were vacuumed out with a Shop-Vac. Fertilizer granules around the bin were blown out with compressed air, and then filled fertilizer bin with the next dry fertilizer treatment. This procedure was followed in all locations to ensure that there will be no cross contamination of fertilizer between treatment applications. The top-dress N source was Urea Ammonium Nitrate (UAN, 28-0-0) applied with streamers nozzles to reduce N losses. All treatments received the same top-dress N in late fall during the last week of November at a rate of 34 kg ha^{-1}. In 2015, there was a single application the first week of February at a rate of 90 kg ha^{-1}. In 2016 spring, N application was split into two different treatments because of lack of moisture during early spring time. First application of 67 kg ha^{-1} was made during the first week of February, and the second application of 67 kg ha^{-1} was made at the first of March. Due to the exceptional spring growing season in 2016, 44 kg N ha-1 more than the year before was applied to maximize yield potential. A Massey Ferguson 8XP combine with a 1.52 m header was used for harvesting the trials. The combine was equipped with a Harvest Master Grain gage to determine plot yield as well as test weight. Sub samples were collected for grain mineral concentration analysis. Statistics were calculated using a mixed model analysis utilizing SAS 9.3 Proc Glimmix. Slice options were used to investigate simple effects when interactions occur. Statistical differences were determined using an alpha=0.05.

The wheat variety used in all research plots is Oklahoma Genetics 'Iba'. Iba is a popular variety in Oklahoma and in Kansas for grain only wheat production. Approximately 1.6% of all acres planted in Oklahoma were planted to Iba (National Agricultural Statistics Service, 2015). This variety has also high disease tolerance and yield capability (Oklahoma Genetics Inc., 2014)

Results

Overall five site-years were analyzed across the three locations. Perkins was not harvested during the 2014-15 year due to significant stand loss from weed competition. The 2014-15 year was an average year for Oklahoma wheat yields, while 2015-16 was an above average year across all three locations. The treatment structure was developed so that multiple comparisons could be made. The following comparisons were analyzed across all locations and measured variables. All fertilizer sources against the fertilized check. If a treatment is not significantly greater than the check then it would suggest there is no response. The three traditional NP sources DAP, MAP and APP. MAP fertilizer was compared to MES10 and MESZ that included secondary and micronutrients. A significant difference of MES10 would suggest an S response while a significant difference between MES10 and MESZ would suggest a Zn response due to Zn being the only difference in the nutrient analysis. MOP was also analyzed against the Mosaic counterpart Aspire, a significant difference with Aspire would indicate a response to B. Also, the two liquid Nachurs fertilizers were compared to each other as well as APP. Lastly, DAP alone was compared to the treated seed that was planted along with DAP. The full list of comparisons and reasons for each are listed in Table 4.

The five site-years were combined and analyzed. Analysis showed there was no significant interactions of YEAR*TRT or LOC*TRT*YEAR, p=0.95 and p=0.28, respectively (Table 5). There was a significant LOC*TRT interactions with a p=0.0008. Due to this interaction results were discussed by location, years were combined across location and year variable was ran as a random effect using Glimmix. Although analysis indicated significant LOC*TRT interaction for this interest of the project the starter treatment yields, test weights and total grain N concentrations were evaluated against the check for all locations. There was no significant treatment effect on any measured parameter (Figure 3.)

Lake Carl Blackwell Research Farm

Lake Carl Blackwell location is one which would be considered a highly productive location with good fertility. Pre-plant soil samples in both years show all nutrients are at or above sufficiency levels (Table 1). Interestingly the plots where moved from the first year to the next they were however just moved next to the previous year's plots. Therefore the drop in soil pH, while still above the recommend minimum value for winter wheat, was un-expected. The 2014-15 crop year had an average grain yield of 3318 kg ha^{-1}, while the 2015-16 growing conditions were much better with an average grain yield of 5941 kg ha^{-1}. Despite difference in average yield across the treatments the range of yield were similar 1004 kg ha^{-1} and 1147 kg ha^{-1} in years 1 and 2 respectively. Standard error for LCB was 1275 kg ha^{-1}. Across both years there was no significant effect of treatment on yield, grain mineral concentration, or test weight when compared to the check (Table 6 & 7). Wheat grain yields among treatments ranged from 4537 to 5309.5 kg ha^{-1}. The average grain yield of LCB was 4952 kg ha^{-1}. When treatments were evaluated by source as described above no significant differences compared to the check were found (Table 6). The check treatment had a grain yield of 5006 kg ha^{-1}.

N40 Research Farm

The N40 location had very low soil test P, and had significant treatment differences among yield, test weight, and grain mineral concentrations. In 2014-15 average grain yield was 2258 kg ha^{-1}, while in 2015-16 cropping season average yield was 4306 kg ha^{-1}. Ranges of treatment yields between the two years were similar with an average of 1873 kg ha^{-1}. No treatments yielded significantly different from the check, but it is worth noting that two fertilizers including both P and S averaged 538 kg/ha more than the check across the two years of research (Table 8). Treatments MAP, MES10, MESZ, and DAP w/Awaken ST yielded significantly better than Awaken ST (3729, 3795, 3824, and 3887 kg ha^{-1}).

Cimarron Valley Research Station

Only one year of data was analyzed for the Perkins location which had both acidic soil condition and low soil test phosphorus values (Table 1). In 2015-16, grain yield ranged from 932 to 3636 kg ha^{-1}. Average yield for the year was 2324 kg ha^{-1}. The standard error for the Perkins location was 1297 kg ha^{-1}. For complete yield values, see Table 11. Treatments DAP, MAP, MES10, MESZ, Nachurs, Nachurs +CG, and DAP with Awaken significantly increased yield above the check by an average of 1395 kg ha^{-1} (Table 10). Interestingly, this was all the P containing treatments with the exception of APP. All treatments but the check and Aspire were significantly greater than Awaken ST. MAP and Awaken ST (0.069 and 0.066 ppm, respectively) were greater than Nachurs for Ca. Also for Ca, MAP was greater than the check (see above). Diammonium phosphate, MAP, Awaken ST, and DAP with Awaken ST were significantly greater in Mn grain mineral concentrations than the check at 53.4, 52.51, 53.23, and 57.88 ppm, respectively (Table 11, α=0.05).

Grain Mineral Concentrations

Although significant differences were found relating to grain mineral concentration, none were related to source of treatment. Table 9 shows significant differences of grain minerals compared to the check. There was not a trend concerning mineral concentrations differences across locations. Within location, significant trends were noticed with Fe being lower in every treatment compared to the check at the N40 location, while Mn was significantly greater with DAP, MAP, MESZ, MOP, Awaken ST, and DAP w/Awaken compared to the check (Table 9).

Discussion

Although some have suggested that high yielding crops even planted into soil with adequate soil fertility at LCB with a very high producing 2015-16 year, no significant differences were observed between the check and the starter fertilizer treatments. There were seven treatments in this experiment that included secondary and or micronutrients. All but two of those treatments included P. There was little recommendation for P at the LCB location. No significant difference was found comparing P fertilizers to the check, as well as comparing P sources to other P treatments. There was also no difference found when comparing within dry P sources as well as within liquid sources, although on average, dry P fertilizer out performed liquid fertilizer. Based on analysis, there was no significant difference or trend that could argue the point that P fertilizer was needed. There was also no significant difference found between treatment 6 and 7 (MOP and Aspire), or between the DAP with Awaken ST or DAP only (treatments 11 and 12) (Figure 4).

N40 represented an area with low soil test P (Table 1), but showed little differences related to the application of P fertilizer. Although not significant, all but one P-containing fertilizers outperformed the check. However, when significance level was evaluated to $\alpha = 0.10$, treatments 5 (MESZ) and 12 (DAP with Awaken) significantly performed better when compared to the check (Table 8). Also, every P source but two outperformed other treatments that did not contain P fertilizer. There were no significant differences comparing treatment 2 and 3 (DAP and MAP), or comparing MAP with treatments 4 and 5 (MES10 or MESZ). On average dry fertilizer performed better than liquid, with the two generic fertilizers treatment 2 and 3 (DAP and MAP) outperforming treatment 10 (APP) by 304 kg ha^{-1}, on average. With the cost of liquid fertilizer typically being higher, based on these results, there should be no reason for a producer to convert to using liquid starter. Within the liquid fertilizers, no significant differences were noticed at N40 location. Treatment 11 (Awaken ST) performed the worse at the N40 location, and was significantly lower than treatments 3, 4, 5, and 12 which were all P-based fertilizers (Figure 5). This would justify the need to take care of nutrient deficiencies before using a product that the fertilizer recommendations do not call for. Other studies are on-going at N40 evaluating this location as its P levels consistently test in the single digits but crops have been historically not responsive to phosphorus fertilizers.

The Perkins location represented an area with low soil pH, as well as coarse-textured soil that may be more susceptible to leaching (Table 1). Over the single year of data collected, there were many significant differences within yield as well as grain mineral concentration. The range of yields for this location was over 2700 kg ha^{-1}. (Table 10) Compared to the check, every P-based fertilizer yielded significantly more except APP. When significance level was adjusted to $\alpha = 0.10$, APP yielded significantly more with an average of 2248 kg ha^{-1} ($P=0.0665$) (Table 10). Agronomically this location needed a P fertilizer for increased grain yields for a higher return on investment. There were no significant differences between generic DAP and MAP fertilizers (treatment 2 and 3), but there was a significant yield difference when comparing MAP to MES10 and MESZ (treatment 4 and 5). At $\alpha=0.05$, MESZ (3637 kg ha^{-1}) outperformed both DAP and

MAP, and at significance level α= 0.10, MES10 (3181 kg ha^{-1}) yielded significantly better than MAP. This could be explained by the possibility of S leaching in the sandy soil in Perkins location. There was no significant difference between DAP and DAP with Awaken seed treatment (treatment 12). When Awaken (treatment 11) was used alone, there was a significant yield loss when compared to all treatments except the check and Aspire (treatment 7). There were no significant differences between liquid P sources, although on average dry P fertilizer outperformed liquid fertilizer (Figure 5). MESZ yielded significantly better than all three liquid P fertilizers (3637 kg ha^{-1}). When adjusted to α=0.10, MES10 (3181 kg ha^{-1}) yielded significantly better than Nachurs (treatment 8). List of significant yield values versus the check for Perkins location can be found in Table 10.

Oklahoma State University's starter fertilizer recommendations are based off soil test results. This experiment follows the guidelines that sound soil test recommendations can be used to determine the need for starter fertilizer in Oklahoma. This study demonstrated that if a soil has adequate nutrient levels, there is no evidence a starter fertilizer will increase grain yields or quality.

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Tables

Table 1. 0-15 cm trial composite pre-plant soil tests for all site years.

Year	Sites	pH	Buffer Index	N	M3 P	K	SO4	Ca	Mg	Fe	Zn	B	Cu
				--------------------------------------ppm--									
2014-15	***LCB***	6.4	6.9	11	47	128	10	720	692	65.3	0.527	0.355	0.919
	N40	6.1	7	6.5	2.61	152	5	1428	342	34.6	0.559	0.191	1.52
2015-16	***LCB***	5.7	7.1	18	50.1	124	5.5	662.5	165	71	0.65	0.309	1.434
	N40	6.3	6.7	11.6	5.8	106	8.6	1660	740	37.8	0.57	0.413	0.88
	Perkins	4.8		5.8	25	166	7.3	495	120	39.1	0.484	0.134	2.91

Table 2. Winter wheat starter fertilizer treatment structure. Rates of fertilizer product applied and resulting amount of each nutrient delivered in-furrow.

			Rate/Additive		Total Amount applied in-furrow (Kg ha-1)									
TRT	Product	Nutrient Analysis	Kg ha^{-1} *L ha^{-1}	L ha^{-1}	N	P	K	S	Zn	Cu	Fe	Mn	Mo	B
1	Check		0	0	0	0	0	0	0	0	0	0	0	0
2	DAP	18-46-0	72.8	0	13.1	14.57	0	0	0	0	0	0	0	0
3	MAP	11-52-0	65	0	7.2	14.75	0	0	0	0	0	0	0	0
4	MES10$	12-40-0-10S	84	0	10	14.66	0	8.4	0	0	0	0	0	0
5	MESZ$	12-40-0-10S-1Z	84	0	10	14.66	0	8.4	0.84	0	0	0	0	0
6	MOP	0-0-60	37	0	0	0	18.4	0	0	0	0	0	0	0
7	Aspire$	0-0-58-.5B	39	0	0	0	18.8	0	0	0	0	0	0	0.195
8	Nachurs^	6-22-6-1S	*116.8	0	9.2	14.75	7.6	1.2	0	0	0	0	0	0
9	Nachurs ^ Corngrow ^	6-22-6-1S + micro	*119.2	2.375	9.4	14.83	7.7	1.2	0.17	0	0.016	0.046	0	0
10	APP	10-34-0	*72.93	0	10	14.92	0	0	0	0	0	0	0	0
11	Awaken&	Seed Treatment	*0.37	0	0.031	0	0.004	0	0.02	0.001	0.001	0.001	<.00001	0.00015
12	DAP + Awaken&	18-46-0 + ST	72.8	0.37*	13.131	14.57	0	0	0.02	0.001	0.001	0.001	<.00001	0.00015

*L ha^{-1}
$ Mosiac Co (Plymouth, Mn)
^ Nachurs Alpine Solutions (Marion, OH)
& Loveland Products (Loveland, CO

Table 3. Salt Index of each treatment. Measured in equivalent weight of materials.

Treatment	Product	Nutrient Analysis	Rate	Salt Index
			Kg ha-1 or L ha-1	Per eq. wt. of material
1	Fertilized Check	0	0	0
2	Diammonium Phosphate (DAP)	18-46-0	72.8	29.2
3	Monoammonium Phosphate (MAP)	11-52-0	65	26.7
4	MES10	12-40-0-10S	84	24.9
5	MESZ	12-40-0-10S-1Z	84	24.9
6	Muriate of Potash (MOP)	0-0-60	37	120.1
7	Aspire	0-0-58-.5B	39	120
8	Nachurs	6-22-6-1S	116.8*	48.9
9	Nachurs + Corngrow	6-22-6-1S	119.2*	48.9
10	Ammonium PolyPhosphate (APP)	10-34-0	72.93	20
11	Awaken (Seed Treatment)	Micronutrient Blend	0	0
12	Awaken + DAP	18-46-0 + Micro	72.8	29.2

*L ha^{-1}

Table 4. Treatment structure was planned so that multiple comparisons could be made. This table lists the treatments to be evaluated utilizing the slice option and the reasoning for the analysis.

Treatments evaluated	Reasoning
1 v 2,3,4,5,6,7,8,9,10,11,12	Response above check
2 v 3 v 10	Evaluation of commonly used nitrogen and phosphorus sources
3 v 4	Response to dry fertilizer source of Sulfur
4 v 5	Response to dry fertilizer source of Zinc
8 v 10	Comparison of traditional liquid Nitrogen and Phosphorus to a low salt multi-nutrient liquid source.
8 v 9	Response to liquid source of copper, manganese and zinc.
2 v 12	Response to a micronutrient seed treatment
6 v 7	Response to dry fertilizer source of boron

Table 5. Location, treatment, and year interaction analyzed via Proc Glimmix to P-value for all site years.

Effect	Num DF	Den DF	F-Value	**Pr** > **F**
LOC	2	118	277.05	<**.0001**
TRT	11	118	3.94	<**.0001**
LOC*TRT	22	118	2.52	**0.0008**
YEAR	1	118	753.20	<**.0001**
YEAR*LOC	1	118	13.52	**0.0004**
YEAR*TRT	11	118	0.40	**0.9520**
YEAR*LOC*TRT	11	118	1.22	**0.2800**

Table 6. Winter wheat grain yields (kg ha^{-1}), grain test weights, and grain nitrogen content (%) from the winter wheat starter fertilizer trials at the Lake Carl Blackwell research farm located near Stillwater, OK for the 2014-16 crop years. Significance based upon alpha= 0.10, 0.05 and 0.01 simple effect comparisons of LOC*TRT Least Squares Means by LOC
Adjustment for Multiple Comparisons: Holm-Tukey utilizing GLIMMIX

Treatment		**Grain Yield (kg ha^{-1})**		**Test Weight**		**Grain N Content (%)**	
1	Check	5006.4		56.13		1.760	
2	DAP	4973.9	NS	56.17	NS	1.733	NS
3	MAP	4846.4	NS	56.04	NS	1.781	NS
4	MES10	5309.5	NS	56.15	NS	1.688	NS
5	MESZ	4805.6	NS	55.93	NS	1.781	NS
6	MOP	4720.6	NS	56.10	NS	1.798	NS
7	Aspire	5236.3	NS	56.45	NS	1.788	NS
8	Nachurs	4693.5	NS	56.14	NS	1.770	NS
9	Nachurs + CG	4536.6	NS	56.01	NS	1.665	NS
10	APP	4860.7	NS	56.11	NS	1.787	NS
11	Awaken ST	5327.6	NS	56.08	NS	1.741	NS
12	DAP w/Awaken	5115.1	NS	56.17	NS	1.740	NS

NS, not significant
@, *, **, significant at the 0.10, 0.05 and 0.01 probability levels, respectively
^ were lower than the check

Table 7. Winter wheat grain yields (kg ha^{-1}), grain test weights, and grain nitrogen content (%) from the winter wheat starter fertilizer trials at the North 40 research located in Stillwater, OK for the 2014-16 crop years. Significance based upon alpha= 0.10, 0.05 and 0.01 simple effect comparisons of LOC*TRT Least Squares Means by LOC Adjustment for Multiple Comparisons: Holm-Tukey utilizing GLIMMIX.

Treatment		**Grain Yield (kg ha^{-1})**		**Test Weight**		**Grain N Content (%)**	
1	Check	3284.8		58.29		2.13	
2	DAP	3510.7	NS	58.03	NS	2.14	NS
3	MAP	3729.0	NS	57.29	*	2.14	NS
4	MES10	3796.0	NS	56.54	**	2.11	NS
5	MESZ	3824.0	@	56.73	**	2.15	NS
6	MOP	3104.1	NS	57.30	*	2.15	NS
7	Aspire	3366.7	NS	56.77	**	2.12	NS
8	Nachurs	3515.7	NS	57.03	**	2.11	NS
9	Nachurs + CG	3221.2	NS	57.11	**	2.09	NS
10	APP	3313.9	NS	56.65	**	2.16	NS
11	Awaken ST	2878.6	NS	57.41	@	2.14	NS
12	DAP w/Awaken	3887.5	@	56.70	**	2.2	NS

NS, not significant

@, *, **, significant at the 0.10, 0.05 and 0.01 probability levels, respectively

^ were lower than the check

Table 8. Winter wheat grain yields (kg ha^{-1}), grain test weights, and grain nitrogen content (%) from the winter wheat starter fertilizer trials at the Cimarron Valley Research station near Perkins Ok for the 2015-16 crop year. Significance based upon alpha= 0.10, 0.05 and 0.01 simple effect comparisons of LOC*TRT Least Squares Means by LOC Adjustment for Multiple Comparisons: Holm-Tukey utilizing GLIMMIX.

Treatment		Grain Yield (kg ha^{-1})		Test Weight		Grain N Content (%)	
1	Check	1398.4		56.60		2.155	
2	DAP	2803.2	**	56.56	NS	1.979	NS
3	MAP	2436.6	*	56.48	NS	2.091	NS
4	MES10	3181.9	**	56.48	NS	1.931	@^
5	MESZ	3637.5	**	56.54	NS	1.958	NS
6	MOP	1954.4	NS	56.65	NS	2.150	NS
7	Aspire	1792.2	NS	56.74	NS	2.065	NS
8	Nachurs	2348.8	*	56.62	NS	1.990	*^
9	Nachurs + CG	2580.6	*	56.50	NS	1.878	NS
10	APP	2248.6	@	56.64	NS	2.049	NS
11	Awaken ST	932.8	NS	56.52	NS	2.150	NS
12	DAP w/Awaken	2578.1	*	56.71	NS	2.070	NS

NS, not significant

@, *, **, significant at the 0.10, 0.05 and 0.01 probability levels, respectively

^ were lower than the check

Table 9. Grain mineral concentration significant differences compared to the check from the winter wheat starter fertilizer trials at the LCB, N40, and Perkins locations near Stillwater, OK for 2014-16 crop years. Analysis performed simple effect comparisons of LOC*TRT Least Square Means. Significance at alpha=0.10#, 0.05*, and 0.01**

	Treatment	LCB	N40	Perkins
2	DAP		P# (Fe**) (Zn#)	Mn*
3	MAP		(Fe**) (Zn*)	Ca* Mg# Mn*
4	MES10		P* Mg# (Fe**)	
5	MESZ		(Fe*)	Mn#
6	MOP		(Fe**)	Mn*
7	Aspire		(Fe**)	
8	Nachurs		(Fe**)	
9	Nachurs +CG	(Mg)#	(Fe**)	S#
10	APP		(Fe**)	
11	Awaken ST	Ca#	(Fe**)	Mn*
12	DAP w/Awaken ST		(Fe**) (Zn#)	Mn**

#, *, ** significant at the 0.10, 0.05, and 0.01 levels, respectively
( ) numbers are significantly lower than the check

Figure

Figure 1. Great Plains no-till drill on 19-cm row spacing with CO_2 in-furrow fertilizer Applicator. Rates controlled by changing orifice plate size and speed of the tractor. Turning on and off starter was controlled by electronic solenoids with a toggle switch located in the cab of the tractor

Figure 2. The Schaffert seed firmer was utilized on the Great Plains no-till drill to deliver the liquid fertilizer. The seed firmer is designed so that the liquid placed next to the seed while the tongue is pressing the seed into the soil to improve seed to soil contact.

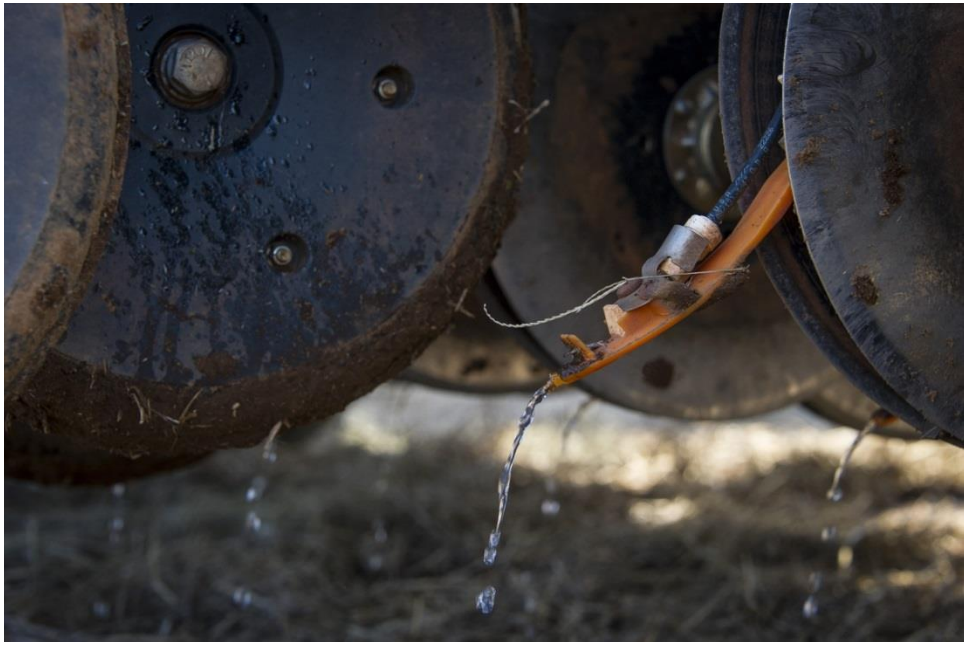


Figure 3. Winter wheat grain yield (kg ha^{-1}) average for each treatment. All site years 2014-15 and 2015-16.

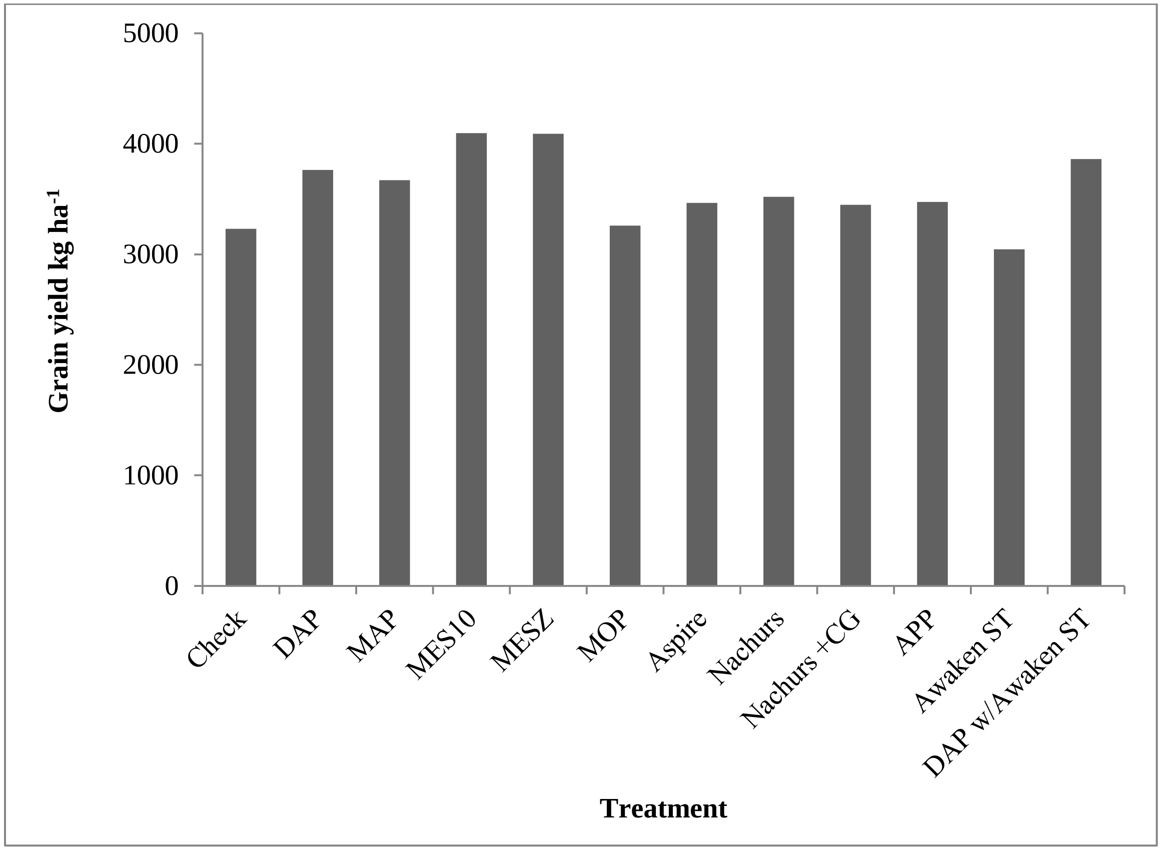


Figure 4. Winter wheat grain yield (kg ha^{-1}) for the starter fertilizer study established at the Lake Carl Blackwell research farm located near Stillwater Ok. Grain yield average across both years.

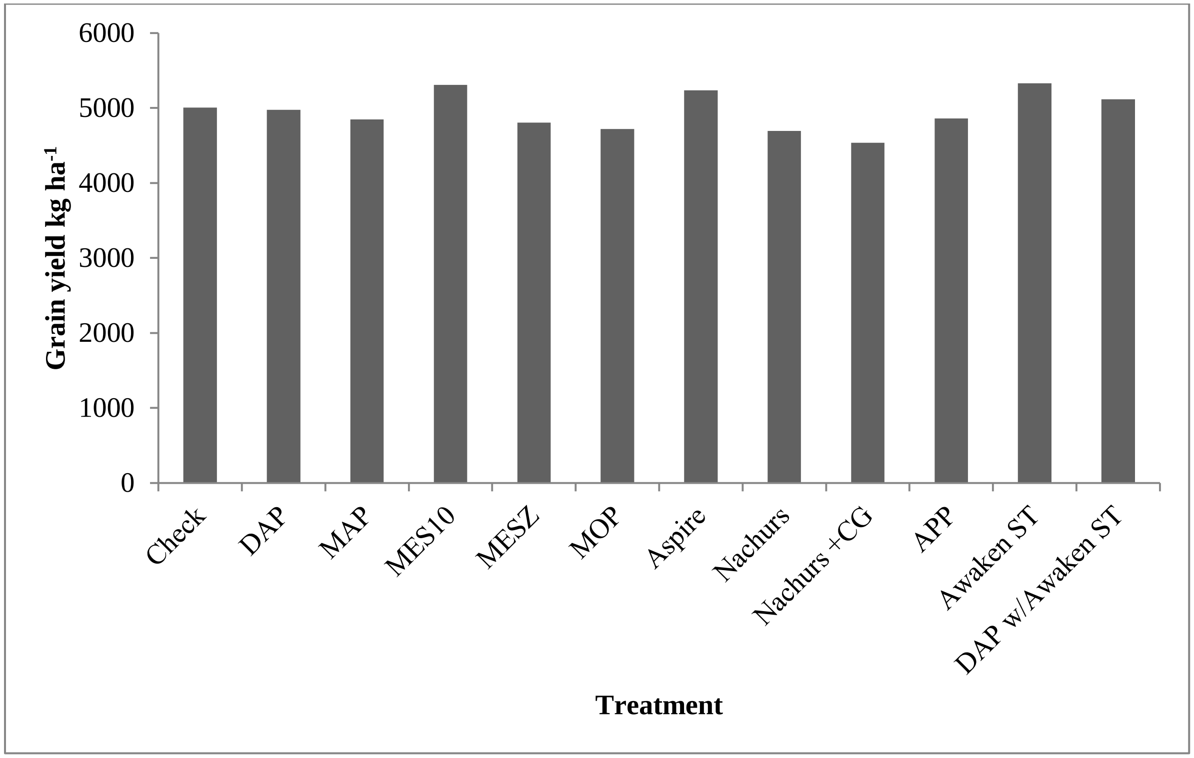


Figure 5. Winter wheat grain yield (kg ha^{-1}) for the starter fertilizer study established at the North 40 research farm located near Stillwater Ok. Grain yield average across both years.

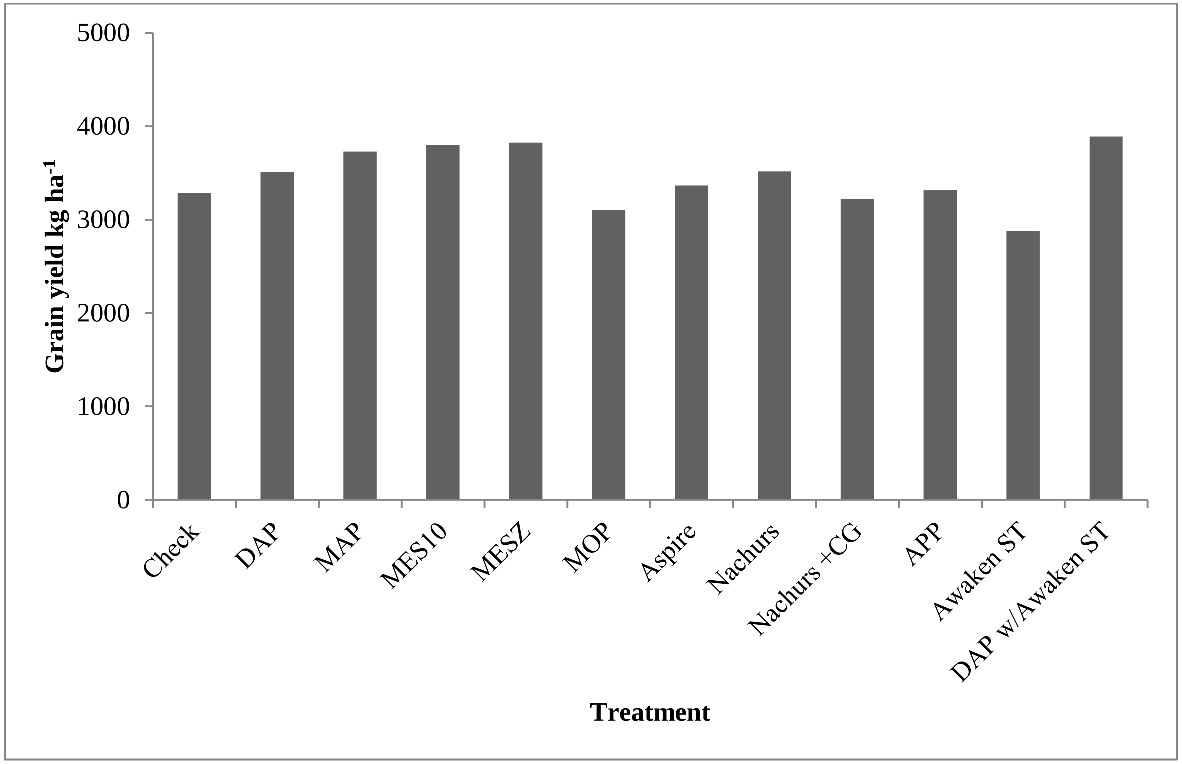


Figure 6. Winter wheat grain yield (kg ha-1) from the 2015-16 cropping season for the starter fertilizer study established at the Cimarron Research Station located near Perkins Ok.

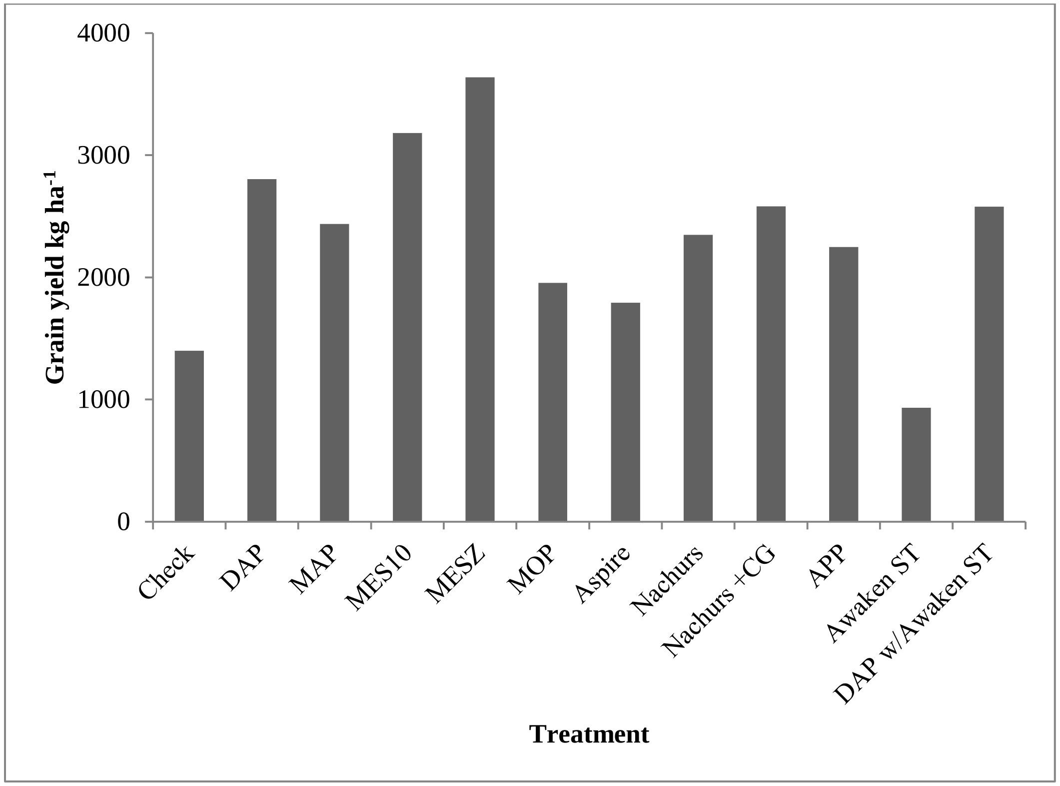
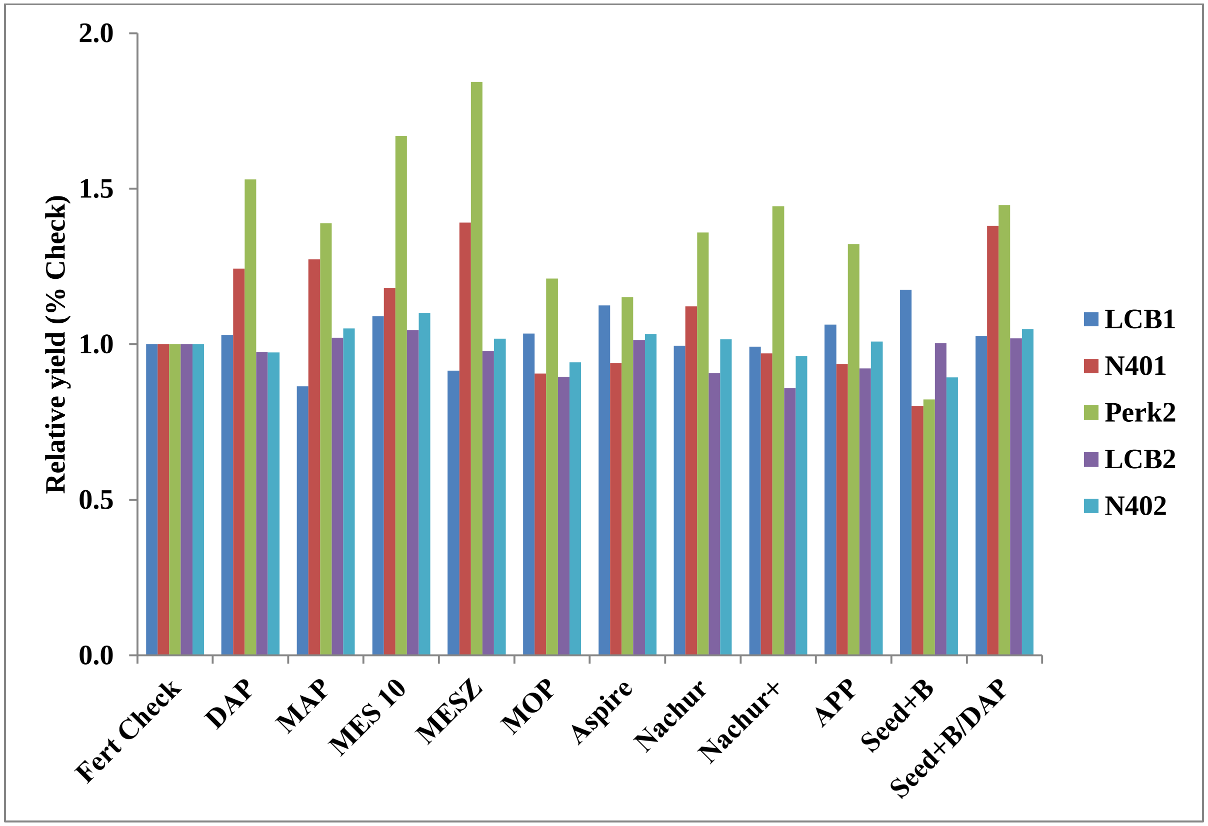


Figure 7. Winter wheat grain yield of each treatment for the starter fertilizer study for all site years relative to the check.



APPENDICES

Appendix 1. Grain mineral concentrations from the winter wheat starter fertilizer trials at the Lake Carl Blackwell research farm located near Stillwater, OK, No treatment created a value significantly greater or less than check plot. Analysis preformed simple effect comparisons of LOC*TRT Least Squares Means by LOC Adjustment for Multiple Comparisons: Holm-Tukey utilizing GLIMMIX.

Treatment	P	Ca	K	Mg	Na	S	Fe	Zn	Cu	Mn	B
1	0.357	0.054	0.352	0.173	0.0012	0.183	76.2	69.10	7.22	48.31	1.11
2	0.409	0.055	0.379	0.183	0.002	0.185	50.8	58.34	6.81	49.93	1.26
3	0.372	0.050	0.347	0.17	0.002	0.183	47.7	54.98	6.68	42.7	1.1
4	0.426	0.058	0.399	0.189	0.00217	0.188	54.5	63.92	7.44	56.88	1.25
5	0.410	0.057	0.382	0.186	0.00217	0.19	56.6	66.18	7.11	51.19	1.35
6	0.336	0.052	0.341	0.165	0.00183	0.181	51.9	64.70	6.90	46.05	1.05
7	0.360	0.053	0.352	0.173	0.00167	0.184	52.6	66.29	7.09	51.18	1.12
8	0.368	0.05	0.346	0.172	0.0015	0.182	51.3	64.54	6.98	47.35	1.32
9	0.348	0.049	0.339	0.166	0.0015	0.177	52.3	61.51	6.85	47.15	0.97
10	0.379	0.053	0.354	0.173	0.00183	0.182	50.4	65.45	6.95	48.88	0.89
11	0.346	0.051	0.336	0.168	0.00183	0.179	53.7	66.39	7.38	47.45	0.96
12	0.397	0.052	0.365	0.179	0.00183	0.185	49.8	58.55	6.81	48.16	0.99

Appendix 2. Grain mineral concentrations from the winter wheat starter fertilizer trials at the North 40 research located in Stillwater, OK for the 2014-16 crop years. No treatment created a value significantly greater or less than check plot. Analysis preformed simple effect comparisons of LOC*TRT Least Squares Means by LOC Adjustment for Multiple Comparisons: Holm-Tukey utilizing GLIMMIX.

Treatment	P	Ca	K	Mg	Na	S	Fe	Zn	Cu	Mn	B
1	0.357	0.054	0.353	0.174	0.00167	0.183	76.2	69.10	7.22	48.31	1.11
2	0.409	0.055	0.379	0.183	0.002	0.186	50.8	58.34	6.81	49.94	1.27
3	0.372	0.050	0.347	0.17	0.002	0.183	47.7	54.98	6.68	42.70	1.10
4	0.426	0.058	0.399	0.189	0.00217	0.186	54.5	63.92	7.44	56.88	1.25
5	0.410	0.057	0.383	0.187	0.00217	0.19	56.6	66.18	7.11	51.19	1.35
6	0.337	0.052	0.341	0.165	0.00183	0.180	51.9	64.70	6.90	46.05	1.05
7	0.360	0.053	0.352	0.173	0.00167	0.184	52.6	66.28	7.09	51.19	1.12
8	0.368	0.05	0.347	0.172	0.0015	0.182	51.3	64.54	6.98	47.35	1.32
9	0.348	0.049	0.339	0.166	0.0015	0.177	52.3	61.51	6.85	47.15	0.996
10	0.379	0.053	0.355	0.173	0.00183	0.182	50.4	65.45	6.96	48.87	0.89
11	0.346	0.051	0.337	0.168	0.00183	0.179	53.7	66.39	7.38	47.45	0.96
12	0.397	0.052	0.365	0.179	0.00183	0.185	49.8	58.55	6.81	48.16	0.99

Appendix 3. Grain mineral concentrations from the winter wheat starter fertilizer trials at the Cimarron Valley Research station near Perkins Ok for the 2015-16 crop year. No treatment created a value significantly greater or less than check plot. Analysis preformed simple effect comparisons of LOC*TRT Least Squares Means by LOC Adjustment for Multiple Comparisons: Holm-Tukey utilizing GLIMMIX.

Treatment	P	Ca	K	Mg	Na	S	Fe	Zn	Cu	Mn	B
1	0.266	0.055	0.360	0.149	0.00144	0.161	41.0	28.45	4.29	37.67	
2	0.329	0.061	0.400	0.161	0.00144	0.155	44.7	29.96	3.66	53.40	1.36
3	0.328	0.069	0.414	0.174	0.00144	0.165	50.3	31.31	4.13	52.51	
4	0.317	0.059	0.386	0.158	0.00144	0.154	45.8	36.19	3.06	49.44	
5	0.322	0.058	0.399	0.161	0.00144	0.156	45.9	40.28	3.29	51.80	
6	0.305	0.062	0.412	0.160	0.00144	0.162	48.3	33.70	4.33	53.62	1.44
7	0.279	0.058	0.369	0.144	0.00211	0.153	45.1	27.68	4.56	42.96	
8	0.305	0.053	0.364	0.150	0.00144	0.151	42.9	27.35	3.61	45.05	
9	0.327	0.053	0.376	0.153	0.00144	0.148	40.4	27.97	3.20	49.20	2.38
10	0.314	0.058	0.401	0.162	0.00144	0.157	46.8	29.83	4.05	49.76	
11	0.318	0.066	0.409	0.164	0.00144	0.167	52.6	35.33	4.73	53.23	2.94
12	0.332	0.063	0.404	0.166	0.00144	0.159	50.2	29.74	4.16	57.88	2.04

VITA

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